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ALFVEN-WAVE DISSIPATION - A SUPPORT MECHANISM FOR QUIESCENT PROMINENCES

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High resolution filtergrams or spectrograms of the main body of quiescent prominences often show a very vivid dynamical picture that cannot be reconciled with static models. Even if large differences exist between individual prominences in this respect, at least parts of the prominence are usually found to be in a "choppy", turbulent state.

Evidence for systematic flows are found in local regions in the prominence and also in the transition zone in the surroundings. These two regions are probably decoupled magnetically.

Alfven waves are generally believed to be responsible for the heating in the upper chromosphere and corona (Hollweg 1986). Since evidence for the presence of Alfven-waves has also been found in the solar wind field, it is highly probable that such waves are generated in the convection zone of the sun and propagated outwards in the solar atmosphere wherever a proper magnetic field is present to carry the waves. The most basic magnetic formations in the solar atmosphere are simple loops. They occur all over the solar surface and cover a large range of magnetic field strengths. Loops with the strongest magnetic fields are found in active regions. It is to be expected that the Alfven-wave flux which is channelled into the loops from below, could show considerable variation both with heliocentric latitude, with time and locally between neighbouring loops.

Let us see what happens when a magnetic loop is exposed to the appropriate Alfven-wave flux required to heat the upper solar atmosphere. Usually a flux of about $5{\times}10^5$ c.g.s. is quoted. The wave-flux may be written:

$$F_A = \frac{1}{2}\,\rho(\Delta V)^2\,V_A = \frac{1}{8\pi}\,(\Delta B)^2\,V_A\ ,$$

where $V_A = B/\sqrt{4\pi\rho}$ is the Alfvén velocity.

For the fluctuations we get:

$$\Delta V = \text{const}\ \rho^{-1/4}\ F_A^{\frac{1}{2}}\ B^{-\frac{1}{2}}\ ,\quad \Delta B = \text{const}\ \rho^{1/4} F^{\frac{1}{2}} B^{-\frac{1}{2}}\ .$$

The measured densities in quiescent prominences are of the order of 10^{-13}g cm^{-3}, about two orders of magnitude higher than in the surrounding corona. Measuremnets of magnetic fields in quiescent prominences, both from using the Zeeman-effect and the Hanle-effect, indicate values in the range from 5 to 12 gauss in the main body. The strongest fields observed are around 20 gauss. In the lower vertical structures, at the footpoints, the few observations available indicate fields of the order of 100 gauss.

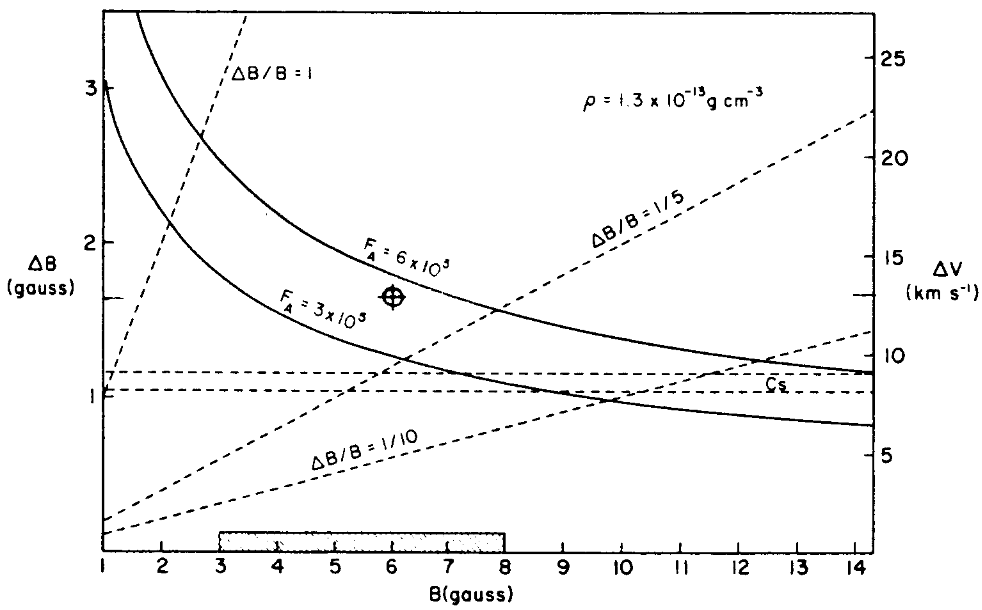

Fig. 1. The magnetic amplitude in the Alfvén wave, ΔB as a function of the carrier field, B, for two values of the flux density, F_A. We have assumed $\rho=1.3\mathrm{x}10^{-13}$g cm^{-3}. The velocity amplitude in the wave, Δv, may be read on the vertical scale to the right. The two horizontal lines indicate the limits for the velocity of sound, C_s, corresponding to temperatures of 6500 and 9000 K. The hatched area indicates the main observed range in $B_{\parallel}$.

These values of the field strengths together with the high observed densities, give Alfven-velocities that are relatively low, of the order of 50-100 km/s in the main body of the prominence. A low Alfven velocity will give large amplitudes for the waves creating a situation similar to a tsunami-wave hitting shallow water, though maybe not quite as dramatic.

This is illustrated in the Figure 1, which shows how the amplitudes ΔB and ΔV vary with the value of the magnetic carrier field B for two values of the wave flux. Choosing B=6 gauss, the amplitudes in the magnetic fluctuation becomes B=1.5 gauss, which corresponds to 25% of the carrier field. The corresponding velocity amplitude is V=13 km/s = 1.6 Cs, where Cs denotes the velocity of sound. Thus the waves can no longer be considered linear, and compressibility effects will be of importance.

Under these conditions a multitude of modes may be created. How fast the various modes decay is difficult to specify, but since compressibility is involved it is good reason to believe that they decay over a much shorter length than ordinary Alfven-waves.

In the dissipation process the momentum lost by the waves is transferred to the matter, providing a stochastic support mechanism for the prominence.

Using expressions for the dissipation lengths given by Wentzel (1977), the dissipation length becomes of the order of 10^2-10^3 km. The resulting force $K_A \sim \frac{1}{2}\rho(\Delta v)^2/L = \frac{F_A}{L\, v_A}$ turns out to be of the right order of magnitude to counteract gravity (Jensen, 1983).

This would mean that the Kippenhahn-Schlüter and similar static models, which relies on smooth magnetic fields with a conveniently located dip at the top could be abandoned altogether.

As appears from the figure one would expect a magnetic loop with a field of the order observed in quiescent prominences to be badly "deformed" or broken up by non-linear effects when a wave-flux of the order required to heat the corona is carried.

For stronger fields, say 25 gauss, $\Delta B/B$ is 3.2%, and for a field of 50 gauss, the relative fluctuation is only 1.1%. A loop with magnetic field of this order will not be much affected by the waves and presumably retain its shape. The sharp lower boundaries of arches sometimes found to join adjacent footpoints may be such an example.

We mentioned that the measured field strength in the prominence "feet" seems to be of the order of 100 gauss. For the fields of this order the relative wave-amplitude would be less than half a percent in keeping with the parallel, ordered structure observed in these features.

The damping of the waves in the prominence "feet" will be less than in the main body, as the damping length for Alfven- waves is very sensitive to the field strength, being proporsional to B to the fourth power. Thus waves ducted into the prominence from below will not suffer strong damping until the amplitude increases strongly in the main body of the prominence.

Both the generation and propagation of the wave-flux into the prominences will show local variations within one and the same prominence. A local increase in the wave-flux will lead to increased heating and at the same time to an enhancement of the supporting force. This would cause a high excitation spectral line in filaments to show different Doppler displacement from lines of low excitation (Engvold et al. 1986). As pointed out by Engvold observations indicate such an effect, when measurements in He 10830Å is compared to the K-line of Ca II. This also fits in with the extended work on filaments as observed in H_α by the French group at Meudon (Malherbe et al. 1981, Malherbe et al. 1983, Martre et al. 1981, Mein 1977, Schneider 1984).

Changes in the wave-flux with phase in the solar cycle could also explain the changes in magnetic fields observed in polar crown prominences (Leroy et al. 1983). With a lower wave-flux at minimum phase a lower magnetic field could be the carrier without being broken up by non-linear effects.

Similarly active region filaments have higher values of their magnetic fields because they are exposed to a stronger wave field. The weaker fields being "shaken" out of existence in or close to active regions.

In my oppinion static models for quiescent prominences are unsatisfactory. It is high time that alternative models emphasizing the observed dynamical aspects are being investigated.

Let us sum up some of the observations that our dynamical, Alfvén-wave model may explain:

<u>The geometry</u> is described as a collection of simple loops, deformed by non-linear effects in the choppy part, where B is low. This is not contrary to the observation by Harvey that prominences show a systematic sign of its magnetic fields. The field is fluctuating and may be highly inhomogeneous, leaving some less perturbed flux tubes to show a systematic direction (Poland et al. 1983). In the arches that have a smooth outline also systematic flow- patterns are found. Here the magnetic field is probably higher.

<u>The velocity-fields</u> in the turbulent part of the prominence are

partly in the supersonic range, making mode-conversion and enhanced dissipation plausible.

The edge-effects observed in the velocity-field finds a natural explanation from the fact that $\Delta V \propto \rho^{-1/4} B^{-1/2}$ and thus should increase in the outer parts. Large ΔV leads to compressibility, and to enhanced dissipation and temperature, resulting in the observed intensity fluctuations.

The support-mechanism is a stochastic process. Matter may rise or fall according to local conditions that change with the time.

A local reshuffling will result rather than a net transfer of matter. Even in places with moderate dissipation, as in the feet of the prominences, matter may rise due to the suction effect created by compression and subsequent cooling in the upper parts of a tube of force.

Further observational tests:
Observations with high spatial resolution of the magnetic field everywhere in the prominences are needed. In particular in the feet knowledge is scanty. Here also velocities should be studied both in filaments away from the center of the disk and on the limb.

Magnetic fluctuations $\Delta B \propto \rho^{1/4} B^{-1/2}$ should be searched for. Simultaneous observations of ΔV and ΔB give an independent determination of the density ρ.

Evolution of microstructure elements, how the thermodynamical parameters change with time, should be investigated from high resolution data.

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